CLIMATOLOGICAL EFFECT OF CHANGEOVER TO HYGROTHERMOMETER

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[Manuscript received May 9, 1961; revised December 14, 1961]

ABSTRACT

The U.S. Weather Bureau is replacing instrument-sheltered thermometers with hygrothermometers. Indications have been received that readings from the old and new installations are in many cases not compatible. Causes and extent of the differences are discussed.

1. INTRODUCTION

A program to install a remote-reading aspirated hygrothermometer in the runway complex at each of a large number of airports was begun by the U.S. Weather Bureau in 1959. This program was intended to serve several purposes: (1) change from instrument shelters which depend on the vagaries of the wind for ventilation to a constantly aspirated instrument; (2) provide more uniform exposure sites for all temperature reading equipment; and (3) satisfy the requirements of aviation for temperature readings as near as possible to the runways. At the present writing, 135 such instruments have been commissioned and the implementation program is still continuing. A drawing and description of the hygrothermometer are shown as figure 1. When the hygrothermometers are commissioned they become the official measuring instruments for temperature and dew point, replacing the louver-sheltered liquid-in-glass thermometers. (These two types of instrument will hereafter be referred to as "hygro" and "shelter".) The changeover involves a change of location as well as one of instrumentation in almost every case.

As the first hygros were commissioned, local Weather Bureau officials and users of the data began to notice that data from the old and new instruments were not always compatible. There was evidence that the change might affect the climatological records and the present study was undertaken to investigate the causes and extent of any differences.

2. DATA

For such an investigation, it was necessary to have a period of overlapping record, that is, concurrent observations from both the old and the new sites and instruments. A few of these were available beginning in May 1960 and the number gradually increased. However, in most cases, the two locations were so widely separated (both horizontally and vertically) that the environmental differences overshadowed any instrumental differences that might exist. It was evident that at least a small number of cases were needed in which both the old (shelter) and the new (hygro) instruments were located side-by-side without environmental differences. Beginning in December 1960, records from a small network of such "adjacent" installations became available for comparison with records at other stations with larger environmental change.

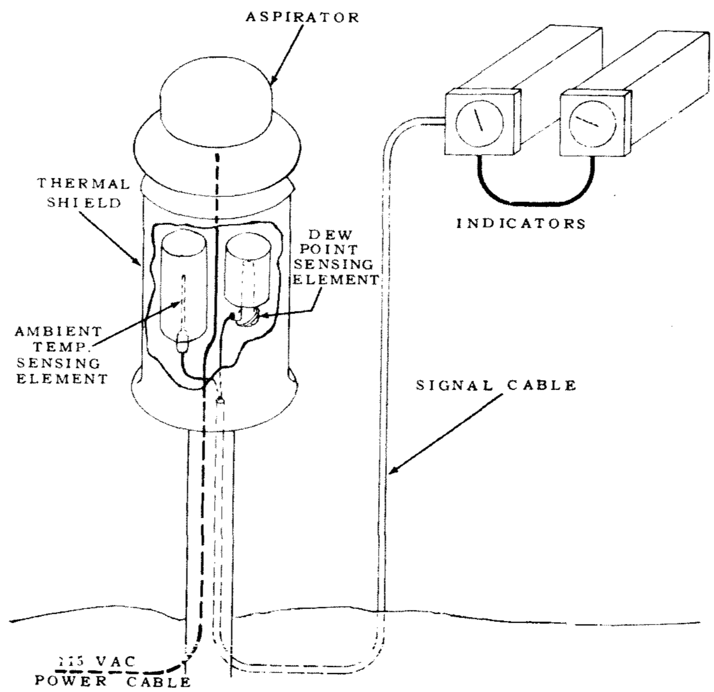

FIGURE 1.—Hygrothermometer being installed at most Weather Bureau airport stations. The system is designed for indicating or recording dew point and ambient air temperatures through the use of remote-registering thermometers. At the exposure site, the sensing thermometers are situated in a continuously aspirated-thermal shield. The dew point thermometer is encased in a lithium chloride cell which is maintained at the lithium chloride dew point of the ambient air by an automatic heating arrangement. Thermometers employed may be of the three-lead resistance type or the liquid-filled type, depending on the telemetering system employed between thermometers and indicators.

The summaries contained in this study are based on data at 19 stations for May, 34 for July, 19 for October, and 61 for December. Data were used for all stations for which comparisons were available for the months of May, July, and December. Data for October were processed after completion of those for other months, and it was then decided to use only a sampling of available data.

3. RESULTS

The data were divided into three groups, which will hereafter be identified as follows:

Group 1. Both instruments on ground, adjacent to each other, 5 stations.

Group 2. Both instruments on ground, nonadjacent, 28 stations.

Group 3. Shelter on roof, hygro on ground, 26 stations.

Symbols used are:

D_x=Hygro-shelter maximum temperature difference on a given day.

$\overline{D}_x$=Mean hygro-shelter maximum temperature difference for the month.

D_n=Hygro-shelter minimum temperature difference on a given day.

$\overline{D}_n$=Mean hygro-shelter minimum temperature difference for the month.

D_m=Hygro-shelter mean temperature difference (the average of D_x and D_n) on a given day.

$\overline{D}_m$=Hygro-shelter mean temperature difference for the month.

$\sigma(\ )$=Standard deviation of variable in parentheses. In all cases + indicates hygro warmer.

Tables 1, 2, and 3 refer to December 1960 from stations in Groups 1, 2, and 3, respectively, and show $\overline{D}_x$, $\sigma(D_x)$, $\overline{D}_n$, $\sigma(D_n)$, and $\overline{D}_m$ for each station in each group, and averaged among all stations in each group. In addition, distances between instruments are shown for stations in Groups 2 and 3, and also height above ground of each instrument for stations in Group 3.

Stations in Group 1 have adjacent instrumental exposures (within 12 feet horizontally and 2 feet vertically). Because of this proximity readings should be practically identical, and any systematic differences should be attributable either to differences between the two observing systems, or to instrumental malfunction. Data for this group indicate that the shelter temperatures average 0.1° F. warmer at time of maximum and the hygro 0.4° F. warmer at time of minimum temperature, also that 96.5 percent of D_x and 91.1 percent of D_n are within 1° F.

TABLE 1.—*Monthly mean differences and standard deviations for Group 1 data (ground stations—adjacent), December 1960*

Station	Mean max. diff. (°F.)	σ max. diff. (°F.)	Mean min. diff. (°F.)	σ min. diff. (°F.)	Monthly mean diff. (°F.)
Anchorage, Alaska	0.0	0.3	+0.7	0.8	+0.4
Detroit, Mich	+0.2	0.9	+0.2	0.7	+0.2
El Paso, Tex	−0.6	0.6	+0.4	0.9	−0.1
Evansville, Ind	−0.1	0.5	+0.2	0.5	0.0
Green Bay, Wis	−0.7	0.5	+0.4	0.7	−0.2
Algebraic mean difference	−0.2		+0.4		+0.1
Mean deviation	0.3		0.4		0.35
Mean standard deviation		0.6		0.7	

+=hygro warmer.

TABLE 2.—*Monthly mean differences and standard deviations for Group 2 data (ground stations—non-adjacent), December 1960*

Station	Distance between instruments (ft.)	Mean max. diff. (° F.)	σ max. diff. (° F.)	Mean min. diff. (° F.)	σ min. diff. (° F.)	Monthly mean diff. (° F.)
Annette, Alaska	1,270	−0.4	0.7	+0.5	0.9	0.0
Atlanta, Ga	4,200	−0.6	1.0	−2.4	1.7	−1.5
Bismarck, N. Dak	3,940	−0.1	1.2	+0.1	1.8	0.0
Burlington, Vt	1,246	−0.5	0.8	−1.2	1.3	−0.8
Charleston, S.C	2,650	+0.7	0.7	−1.3	1.6	−0.3
Charleston, W. Va	1,500	−0.8	0.9	+0.1	0.7	−0.4
Cheyenne, Wyo	1,550	−1.4	1.4	−1.2	1.2	−1.3
Daytona Beach, Fla	477	−0.3	0.6	−0.6	1.1	−0.4
Denver, Colo	5,160	−2.6	2.1	−3.5	2.7	−3.1
Fort Myers, Fla	1,960	+0.5	0.6	+1.0	0.8	+0.8
Huron, S. Dak	1,962	−1.6	1.0	−1.2	1.0	−1.4
Las Vegas, Nev	2,350	−1.4	1.2	+0.5	0.6	−0.4
Memphis, Tenn	1,520	−0.3	0.9	−1.6	1.7	−1.0
Milwaukee, Wis	2,000	−0.1	0.6	−0.1	1.0	−0.1
Muskegon, Mich	2,640	+0.3	0.8	+0.5	1.3	+0.4
Pendleton, Oreg	1,220	0.0	0.8	+0.1	0.6	0.0
Phoenix, Ariz	3,900	+0.5	0.7	−3.3	1.2	−1.4
Pittsburgh, Pa	2,550	−1.4	1.2	−0.9	1.0	−1.2
Richmond, Va	2,650	+1.0	1.2	+0.5	1.5	+0.8
Sacramento, Calif	1,840	+0.2	0.5	+0.1	0.5	+0.1
Salt Lake City, Utah	3,850	−1.4	1.4	−1.2	1.5	−1.3
Seattle-Tacoma, Wash	1,724	−0.1	0.8	−0.2	0.9	−0.2
Spokane, Wash	2,260	−0.9	0.8	−1.0	1.2	−1.0
Springfield, Ill	2,000	−0.5	0.9	−1.0	1.2	−0.8
Washington, D.C	2,400	−1.0	1.1	−0.3	1.0	−0.6
Waterloo, Iowa	1,850	+0.2	0.7	−0.4	1.3	−0.1
Windsor Locks, Conn	2,080	−0.5	0.9	−0.8	1.3	−0.6
Youngstown, Ohio	1,700	−0.3	0.8	+0.4	1.0	0.0
Algebraic mean difference		−0.4		−0.6		−0.5
Mean deviation		0.7		0.9		0.7
Mean standard deviation			1.0		1.3	

+=hygro warmer.

TABLE 3.—*Monthly mean differences and standard deviations for Group 3 data (non-adjacent—shelter on roof, hygro on ground), December 1960.*

Station	Distance between instruments (ft.)	Height inst. shelter (ft.)	Height hygro (ft.)	Mean max. diff. (° F.)	σ max. diff. (° F.)	Mean min. diff. (° F.)	σ min. diff. (° F.)	Monthly mean diff. (° F.)
Albuquerque, N. Mex	4,752	16	5	−1.0	1.4	+0.7	1.5	−0.2
Baton Rouge, La	1,300	22	4	−1.8	1.4	−1.6	1.0	−1.7
Billings, Mont	1,500	29	4	−0.7	1.0	+0.7	1.2	0.0
Charlotte, N.C	2,230	21	5	−0.5	1.1	−0.9	0.9	−0.7
Chicago, Ill	3,280	39	4	−0.7	0.9	−1.1	2.0	−0.9
Cleveland, Ohio	3,940	28	4	−1.6	1.0	−2.3	1.9	−2.0
Colorado Springs, Colo	1,650	20	6	−2.5	1.2	+0.1	1.3	−1.2
Columbus, Ohio	2,640	39	4	+0.4	0.8	+0.1	1.7	+0.2
Dallas, Tex	1,400	49	5	−0.5	0.7	0.0	0.8	−0.2
El Paso, Tex	4,000	31	4	−2.2	1.4	−1.8	1.5	−2.0
Fargo, N. Dak	1,730	18	5	+0.3	1.0	−0.4	1.5	0.0
Greenville, S.C	1,850	21	5	+1.4	1.1	−0.4	1.5	+0.5
Kalispell, Mont	1,700	25	4	−2.5	1.9	−2.7	2.1	−2.6
Kansas City, Mo	1,450	39	4	−1.0	1.1	−1.7	1.7	−1.4
Little Rock, Ark	2,050	30	5	−0.8	0.9	−3.0	2.1	−1.9
Louisville, Ky	2,145	17	6	−1.0	1.1	−1.5	1.3	−1.2
Madison, Wis	3,200	28	5	0.0	1.0	−0.7	1.3	−0.4
Missoula, Mont	1,700	16	6	−2.4	1.8	−3.4	2.0	−2.9
Moline, Ill	2,000	36	5	−0.7	1.0	−1.7	1.9	−1.2
Montgomery, Ala	2,200	26	4	−1.7	1.3	−0.7	1.4	−1.2
Olympia, Wash	1,660	35	5	−0.1	0.6	−0.4	1.2	−0.2
San Angelo, Tex	2,080	49	6	+1.4	0.7	+0.1	1.6	+0.8
Sioux City, Iowa	1,650	19	3	+0.5	0.9	−0.1	1.4	+0.2
Springfield, Mo	1,743	25	5	+0.1	1.0	−0.2	1.1	0.0
Toledo, Ohio	2,400	20	4	−1.4	0.8	−2.2	1.4	−1.8
Winslow, Ariz	2,050	18	3	−1.6	1.9	−0.9	1.7	−1.2
Algebraic mean difference				−0.8		−1.0		−0.9
Mean deviation				1.1		1.1		1.0
Mean standard deviation					1.2		1.5	

+=hygro warmer.

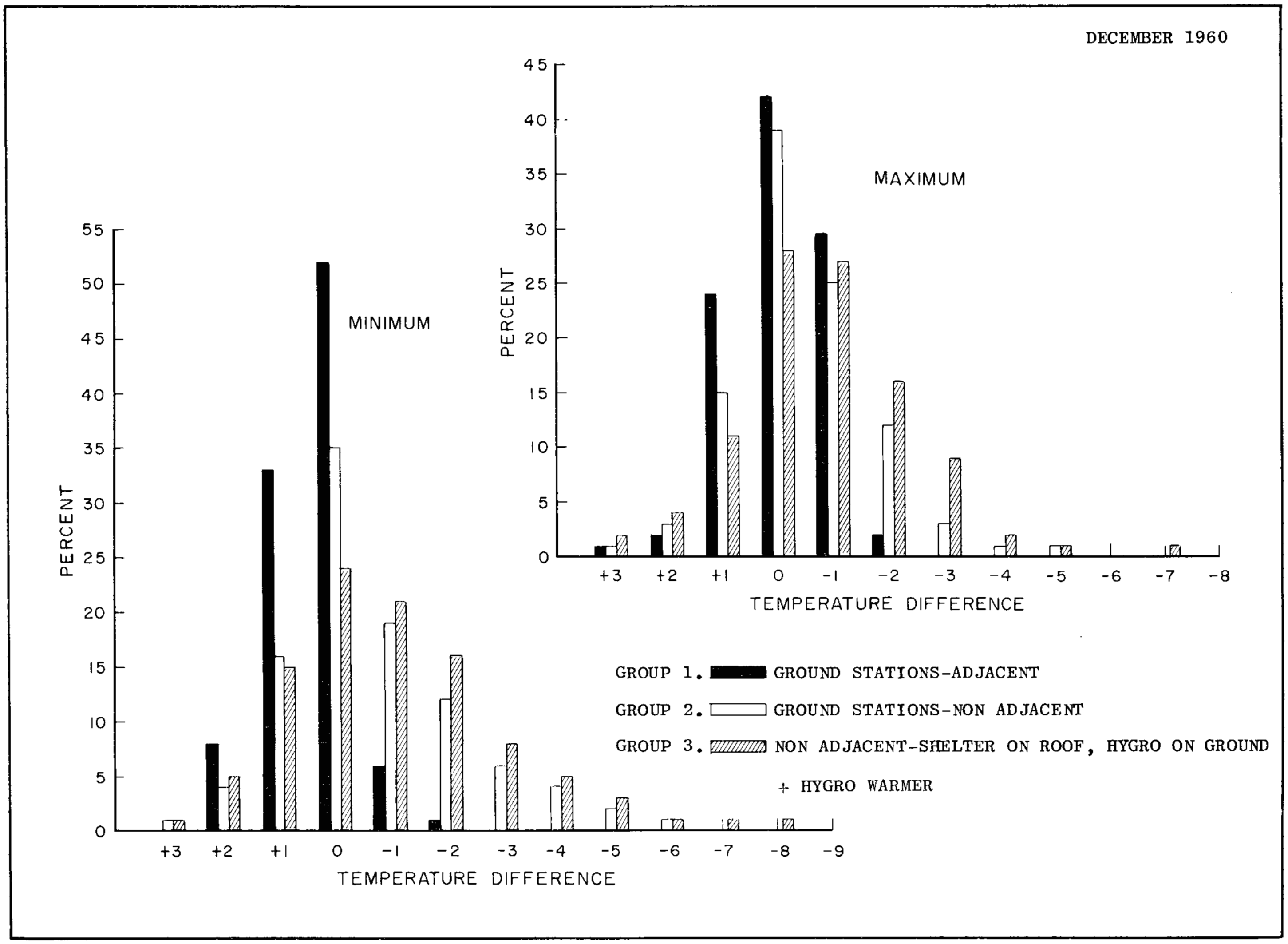

Figure 2.—Percentage frequency of various amounts of difference in maximum and minimum temperature between the shelter and hygrothermometer installations for the three groups of stations.

Perhaps a small portion of the deviations shown in table 1 can be attributed to the small differences in height indicated above, particularly during times of intense but very shallow inversions. Part may be due to the fact that each instrument is read independently to the nearest whole degree. Another portion can undoubtedly be explained by the lack of perfect calibration in individual instruments, with particular emphasis on the hygro. The remainder could be due to retained insolation in the shelter, particularly during times of light wind and clear skies.

The pairs of instruments at stations in Group 2 are separated by horizontal distances varying from 500 to 5,000 feet, but are both near the ground. Those in Group 3 are separated by similar horizontal distances and, in addition, are at different heights above ground. Although microclimatological (environmental) differences between pairs of instruments in Group 1 are extremely small, it is evident that differences are larger at stations in Group 2 and largest at stations in Group 3. It will be noted that El Paso is listed in both Groups 1 and 3. These entries represent two different shelters.

In table 4 are presented comparative summarized data from the first three tables. The effect of increased en-

Table 4.—*Comparative summarized data from tables 1, 2, and 3, December 1960*

	Group 1 5 stations ground adjacent	Group 2 28 stations ground non-adjacent	Group 3 26 stations roof to ground
Algebraic difference (°F.)			
Mean max	−0.2	−0.4	−0.8
Mean min	+0.4	−0.6	−1.0
Mean	+0.2	−0.5	−0.9
Deviation (°F.)			
Mean max	0.3	0.7	1.1
Mean min	0.4	0.9	1.1
Mean	0.35	0.7	1.0
Standard deviation (°F.)			
Max. temp	0.6	1.0	1.2
Min. temp	0.7	1.3	1.5
Percent within ±1°			
Max. temp	96.5	80.7	64.3
Min	91.1	70.4	59.6
Mean	93.8	75.5	62.0

+ = hygro warmer.

TABLE 5.—*Mean differences and frequency distributions of differences for Group 2 data (ground stations—non-adjacent), July 1960*

	Distance between instruments	Mean max temp. diff.	Mean min. temp. diff.	Monthly mean diff.	Freq. dist. of maximum temp. diff. +3	+2	+1	0	−1	−2	−3	−4	Freq. dist. of minimum temp. diff. +5	+4	+3	+2	+1	0	−1	−2	−3	−4	−5
Bismarck, N. Dak.	3,940	+0.4	−0.5	0.0		3	12	10	5	1						5	6	8	2	5	2	2	1
Burlington, Vt.	1,246	+0.7	−1.7	−0.5	1	4	11	13	2									6	3	13	7	2	
Cheyenne, Wyo.	1,550	+1.7	+0.9	+1.3	7	9	13	2								9	11	10					
Daytona Beach, Fla.	477	−1.3	−0.3	−0.8			1	4	13	10	3						1	19	11				
Huron, S. Dak.	1,962	+0.7	−1.1	−0.2		7	11	10	2	1							3	13	4	4	4	2	
Las Vegas, Nev.	2,350	−1.0	+0.4	−0.3			2	4	17	6	1	1	1	0	2	2	6	15	4	1			
Richmond, Va.	2,650	+0.8	−1.1	−0.4	2	8	8	9	4								2	10	9	5	3	2	
Salem, Oreg.	630	−0.2	−0.7	−0.4			8	22	1									14	13	3	1		
Salt Lake City, Utah	3,850	+1.5	+0.5	+1.0	1	15	13	2							3	3	10	10	3	1		1	
Seattle-Tacoma, Wash.	1,724	+1.0	−0.3	−0.4	1	9	13	7	1								9	9	10	2	1		
Springfield, Ill.	2,000	+1.4	−0.7	+0.4	2	13	11	4	1								4	9	12	5	1		
Waterloo, Iowa	1,850	−0.2	−0.8	−0.5		1	4	15	10	1								8	17	3		1	
Youngstown, Ohio	1,700	−0.4	−0.1	−0.2			1	9	5	1						1	1	10	3	1			
New Orleans, La.	2,800	−1.4	−1.5	−1.5			1	6	8	11	3	1				1	2	3	10	8	3	2	
Anchorage, Alaska	12	0.0	+0.5	+0.2			3	27	1							3	10	16	2				
Sum of difference		+3.7	−6.5																				
Mean Difference		+0.2	−0.4																				
Total					14	69	112	144	70	31	7	2	1	0	5	24	65	160	103	51	22	12	3
Percent					3.1	15.4	24.9	32.1	15.6	6.9	1.6	0.4	0.2	0.0	1.1	5.4	14.6	35.9	23.1	11.4	4.9	2.7	0.7

+ = hygro warmer.

TABLE 6.—*Mean differences and frequency distributions of differences for Group 3 data (shelter on roof, hygro on ground), July 1960*

	Height of shelter (ft.)	Height of hygro (ft.)	Distance between instruments (ft.)	Mean max. temp. diff. (°F.)	Mean min. temp. diff. (°F.)	Monthly mean diff. (°F.)	Freq. dist. of maximum temp. diff. +6	+5	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7
Albuquerque, N. Mex.	16	5	4,752	+0.4	+1.4	+0.9				2	2	11	9	5	2					
Cleveland, Ohio	28	4	3,940	−1.8	−3.6	−2.7						2	1	8	5	8	1			
Colorado Springs, Colo.	20	6	1,650	−1.0	0.0	−0.5						6	2	9	11	1				
Columbus, Ohio	39	4	2,640	−0.7	+0.2	−0.3					2	7	5	6	6	4	1			
Dallas, Tex.	49	5	1,430	−0.9	+0.2	−0.4							12	11	7	1				
Greenville, S.C.	21	5	1,850	+1.4	+1.1	+1.2			1	5	7	11	5	2						
Kalispell, Mont.	25	4	1,700	+2.4	−2.1	+0.2		2	5	7	9	6	2							
Little Rock, Ark.	30	5	2,050	−0.5	−0.9	−0.7				1	2	3	11	6	6	2				
Louisville, Ky.	17	6	2,145	−4.6	−2.3	−3.5									4	5	6	6	4	6
Madison, Wis.	28	5	3,200	−2.9	−1.1	−2.0							2	5	4	9	7	3	0	1
Minneapolis, Minn.	47	5	2,250	−1.8	−2.7	−2.3						2	6	10	5	5	2	1		
Missoula, Mont.	16	6	1,700	+2.1	−2.7	−0.3			2	12	10	3	3	1						
Moline, Ill.	36	5	2,000	−0.1	−0.4	−0.3				1	1	5	15	5	3	1				
Montgomery, Ala.	26	4	2,200	−1.0	+1.6	+0.3						2	8	11	9	1				
Olympia, Wash.	35	5	1,660	+1.2	−1.4	−0.1			2	0	9	13	4	2						
San Angelo, Tex.	49	6	2,080	+4.3	+1.0	+2.6	3	12	8	7	1									
Springfield, Mo.	25	5	1,743	+0.7	−1.7	−0.5				2	7	7	9	2	1		1			
Toledo, Ohio	20	4	2,400	−0.3	−1.1	−0.7					1	10	4	11	4	1				
Winslow, Ariz.	18	3	2,050	+0.9	0.0	+0.5				2	6	13	6	4						
Sum of differences				−2.2	−14.5															
Mean difference				−0.1	−0.8															
Total							3	14	18	39	57	101	104	98	67	38	18	10	4	7
Percent							0.5	2.4	3.1	6.7	9.9	17.5	18.0	17.0	11.6	6.6	3.1	1.7	0.7	1.2

	Height of shelter (ft.)	Height of hygro (ft.)	Distance between instruments (ft.)	Mean max. temp. diff. (°F.)	Mean min. temp. diff. (°F.)	Monthly mean diff. (°F.)	Freq. dist. of minimum temp. diff. +6	+5	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7
Albuquerque, N. Mex.	16	5	4,752	+0.4	+1.4	+0.9	1	1	4	5	3	7	4	3	1	1	1			
Cleveland, Ohio	28	4	3,940	−1.8	−3.6	−2.7								1	3	9	6	5		1
Colorado Springs, Colo.	20	6	1,650	−1.0	0.0	−0.5					1	8	9	10	1					
Columbus, Ohio	39	4	2,640	−0.7	+0.2	−0.3					2	7	16	6						
Dallas, Tex.	49	5	1,400	−0.9	+0.2	−0.4						7	23	1						
Greenville, S.C.	21	5	1,850	+1.4	+1.1	+1.2				1	13	7	8	2						
Kalispell, Mont.	25	4	1,700	+2.4	−2.1	+0.2							2	8	12	6	2		1	
Little Rock, Ark.	30	5	2,050	−0.5	−0.9	−0.7					1	2	13	7	4	2	1			
Louisville, Ky.	17	6	2,145	−4.6	−2.3	−3.5							4	3	9	11	3	1		
Madison, Wis.	28	5	3,200	−2.9	−1.1	−2.0						2	6	14	6	3				
Minneapolis, Minn.	47	5	2,250	−1.8	−2.7	−2.3							3	7	3	9	5	1	2	1
Missoula, Mont.	16	6	1,700	+2.1	−2.7	−0.3							3	2	8	8	9	1		
Moline, Ill.	36	5	2,000	−0.1	−0.4	−0.3					2	2	12	10	5					
Montgomery, Ala.	26	4	2,200	−1.0	+1.6	+0.3				3	12	12	3							
Olympia, Wash.	35	5	1,660	+1.2	−1.4	−0.1						2	6	6	12	1	3			
San Angelo, Tex.	49	6	2,080	+4.3	+1.0	+2.6				5	7	9	6	2	1	1				
Springfield, Mo.	25	5	1,743	+0.7	−1.7	−0.5							5	10	7	5	3			
Toledo, Ohio	20	4	2,400	−0.3	−1.1	−0.7					1	3	5	7	11	3	1			
Winslow, Ariz.	18	3	2,050	+0.9	0.0	+0.5					2	11	8	7	2	1				
Sum of differences				−2.2	−14.5															
Mean difference				−0.1	−0.8															
Total							1	1	4	14	44	79	136	106	85	60	34	8	3	2
Percent							0.2	0.2	0.7	2.4	7.6	13.7	23.6	18.4	14.7	10.4	5.9	1.4	0.5	0.3

+ = hygro warmer

TABLE 7.—*Wind and cloud effect on temperature differences, December 1960*

	Average wind and cloud effect									Average wind effect with all clouds			Average cloud effect with all winds		
	Wind 0–4 kt.			Wind 5–9 kt.			Wind ≥10 kt.			Wind (kt.)			Clouds (tenths)		
	Clouds (tenths)			Clouds (tenths)			Clouds (tenths)								
	0–3	4–7	8–10	0–3	4–7	8–10	0–3	4–7	8–10	0–4	5–9	≥10	0–3	4–7	8–10
Maximum Temperature															
Group 1	0.0	+1.0	+0.2	−0.2	+0.2	+0.1	+0.1	+0.6	+0.3	+0.2	+0.5	+0.3	−0.2	+0.5	+0.3
Group 2	-------	−1.0	−0.8	−0.4	−0.1	−0.6	−0.4	−0.5	−0.4	−0.9	−0.4	−0.4	−0.4	−0.4	−0.5
Group 3	−3.9	−3.0	−1.5	−1.8	−1.8	−1.2	+0.9	+0.6	+0.1	−2.6	−1.6	+0.5	−1.9	−0.8	−1.0
Minimum Temperature															
Group 1	0.0	+0.7	+0.3	+0.1	+0.7	+0.5	+0.7	+0.5	+0.7	+0.2	+0.3	+0.6	+0.4	+0.6	+0.6
Group 2	−2.1	−0.7	−0.2	−1.8	−1.8	−0.7	−1.1	−1.1	−0.4	−1.6	−1.4	−0.8	−1.7	−1.3	−0.6
Group 3	−3.3	−2.5	−1.3	−1.8	−2.8	−0.2	−1.3	+1.0	+1.1	−2.4	−1.4	+0.2	−2.2	−2.4	−0.3

Note: Wind and cloud data based on time of occurrence of the daily maximum and minimum temperature (6-hour average).

+=hygro warmer

Group 1 Ground stations Adjacent

Anchorage, Alaska
Detroit, Mich.
Evansville, Ind.
Duluth, Minn.
Green Bay, Wis.

Group 2 Ground stations Non-adjacent

Bismarck, N. Dak.
Burlington, Vt.
Charleston, S.C.
Memphis, Tenn.
Pittsburgh, Pa.
Springfield, Ill.

Group 3 Roof-to-ground

Colorado Springs, Colo.
Little Rock, Ark.
Missoula, Mont.
San Angelo, Tex.
Winslow, Ariz.

vironmental differences going from Group 1 to 2 to 3 can be seen in the increased mean values and standard deviations of the differences, and the decreased percentages of D_x and D_n within $\pm 1°$ F. It should be noted that $\overline{D}_n$ values are larger than those of $\overline{D}_x$ in every case. Histograms of D_x and D_n which are shown as figure 2 again clearly illustrate these relationships.

Tables 5 and 6 show mean differences and frequencies of temperature difference for the month of July 1960, for networks of stations in Groups 2 and 3, respectively. Unfortunately, data similar to those in table 1 could not be prepared for the month of July, as hygros had not yet been installed at most of the stations with adjacent installations. Although values of $\overline{D}_x$ show but little deviation from zero in both the surface (table 5) and roof-to-surface (table 6) groups, values of $\overline{D}_n$ have doubled in the latter group. However, the larger range of differences in the roof-to-ground stations can be seen in the frequency distributions shown in tables 5 and 6.

Daily values of D_x and D_n are not constant and their variations are definitely related to synoptic situations. This is demonstrated in table 7, in which average values of D_x and D_n for selected stations in Groups 1, 2, and 3 are compared for various wind and cloud conditions for the month of December 1960. This table indicates that the magnitudes of D_x and D_n tend to be greatest under conditions of light winds and clear skies and least under high-speed winds and overcast conditions.

Figures 3 and 4 show the cumulative probability of $(D_x-\overline{D}_x)$ and $(D_n-\overline{D}_n)$ respectively, each for Groups 1, 2, and 3. Examples of use of these charts are as follows: (1) From figure 4, the probability of a departure of minimum temperature greater than 2° F. for Group 1 is 0.5 percent, for Group 2, 13 percent, and for Group 3, 18 percent. (2) Again from figure 4, the maximum $D_n-\overline{D}_n$ values that are exceeded 10 percent of the time are 1.2° for Group 1, 2.2° for Group 2, and 2.5° for Group 3.

Other exhibits of interest are tables 8, 9, and 10 showing frequency distributions by groups of D_x and D_n for each of the 59 stations whose December 1960 records were used in this study. The instruments are read to whole degrees and therefore the +1, 0 and −1 columns may be added together to indicate the number of cases of no important difference. By this definition, in Group 1 only 5 percent of the D_x and 9 percent of the D_n are different. In Group 2 the corresponding figures are 21 percent and 30 percent, and in Group 3 they are 35 percent and 41 percent. There are large differences in magnitude and also differences in sign between various stations. Table 11 shows comparative $\overline{D}_x$ and $\overline{D}_n$ data for a small network of stations for mid-months of each season, for which processed data were available. Again there are wide variations between stations, but the number of cases in Groups 2 and 3 with mean monthly differences between hygro and shelter of 1° and 2° or more is disturbingly large. Extremes are −4.6° in July at Louisville and +4.3° in July at San Angelo.

TABLE 8.—*Frequency distribution of temperature differences for Group 1 data (ground stations—adjacent), December 1960*

	Maximum						Minimum				
	+3	+2	+1	0	−1	−2	+2	+1	0	−1	−2
Anchorage, Alaska		2	27	1			6	13	10	1	
Detroit, Mich	1	1	6	19	3	1		9	19	2	1
El Paso, Tex*				14	16	1	4	9	14	4	
Evansville, Ind			2	17	5			6	17	1	
Green Bay, Wis				11	19	1	2	11	17	1	
Total	1	3	35	62	43	3	12	48	77	9	1
Percent	1	2	24	42	29	2	8	33	52	6	1

*January 1961 data
+=hygro warmer

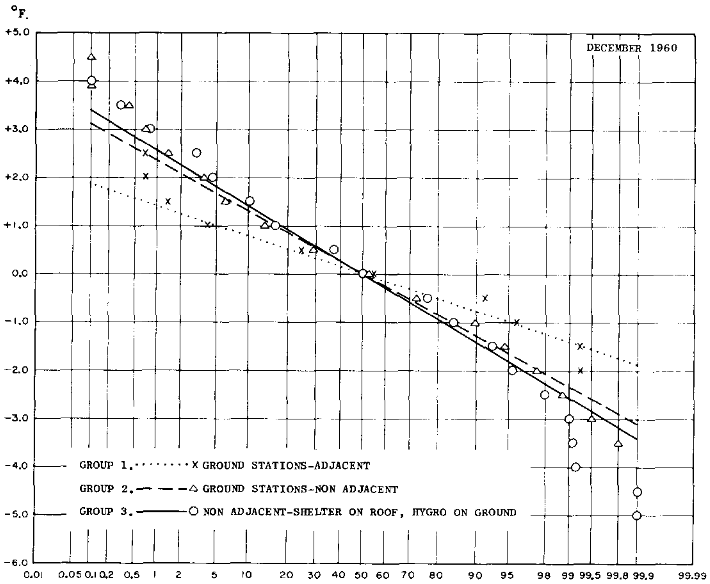

FIGURE 3.—Cumulative probability of exceedance of given $(D_x-\overline{D}_x)$ values, based on December 1960 data for the three groups of stations.

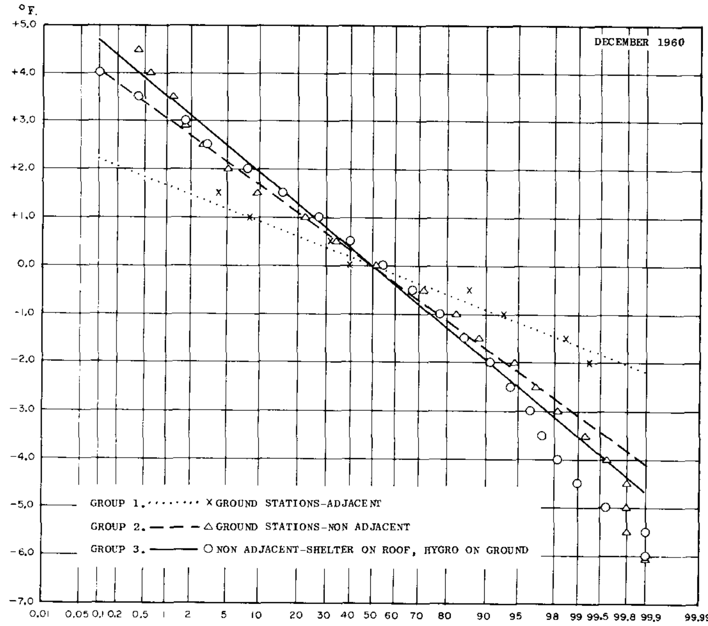

FIGURE 4.—Cumulative probability of exceedance of given $(D_n-\overline{D}_n)$ values, based on December 1960 data.

Table 12 is composed of statements regarding shelter and hygro exposures which have been extracted from correspondence with observing stations. This indicates that many of the old shelter exposures were influenced by extraneous effects and, in those cases, the move to a location in the runway complex undoubtedly improved the exposure. However, it is also apparent that in a few cases the new hygro exposure is not entirely free from undesirable influences.

4. CONCLUSIONS

(1) Comparative temperature differences between hygro and shelter thermometers are primarily due to differences in instrumental environment. A comparative temperature study for the month of December 1960 at 59 stations shows increased differences with increased contrast in environment. Values of $\overline{D}_x$ and $\overline{D}_n$ are greater at stations that made a horizontal move in instrumentation than at

TABLE 9.—*Frequency distribution of temperature differences for Group 2 data (ground stations—non-adjacent), December 1960.*

	Maximum											Minimum															
	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	+5	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10
Annette, Alaska				2	12	14	1							1	2	9	13	3									
Atlanta, Ga			1	1	14	8	7										4	7	9	2	4	4	1				
Bismarck, N. Dak			1	11	9	6	2	2						3	7	2	8	4	5	1	1						
Burlington, Vt				4	10	16	1									2	9	8	7	4		1					
Charleston, S.C			3	16	11	1									3	1	5	6	9	5	2						
Charleston, W. Va				1	8	9	4	1							1	5	13	4									
Cheyenne, Wyo				2	5	6	15	1		1						1	10	9	5	5	1						
Daytona Beach, Fla				2	20	8	1									3	13	10	3	1	1						
Denver, Colo			1	1	4	5	3	4	5	6	2					3	4	1	3	1	5	7	4	2			1
Fort Myers, Fla				14	11	1									6	15	1	2									
Huron, S. Dak			1		1	11	15	2	1								10	10	7	4							
Las Vegas, Nev			1		4	13	5	7							1	13	16	1									
Memphis, Tenn			2	2	13	12	2									3	7	6	6	3	4	2					
Milwaukee, Wis				4	20	7										11	10	6	4								
Muskegon, Mich		1	2	5	21	2								1	5	8	15	1				1					
Pendleton, Oreg			1	6	15	9										7	21	3									
Phoenix, Ariz			1	9	8	1											1		3	6	8		1				
Pittsburgh, Pa				1	5	13	8	2	1	1						3	8	9	10	1							
Richmond, Va	1	3	4	11	10	2						1		1	4	8	10	6		1							
Sacramento, Calif				8	22	1										6	23	2									
Salt Lake City, Utah			1	3	4	3	15	4	1					1		3	5	9	7	4	2						
Seattle-Tacoma, Wash			1	4	19	6	1								1	4	15	9	2								
Spokane, Wash					10	14	6	1								3	10	8	5	5							
Springfield, Ill				3	11	12	4	1								3	9	9	7	2	1						
Washington, D.C				3	7	12	7	1	1							8	10	10	3								
Waterloo, Iowa			1	8	19	3										7	14	7		1	2						
Windsor Locks, Conn				3	16	8	3	1						1		2	10	9	6	2	1						
Youngstown, Ohio			1	1	18	9		1						1	3	7	16	2	1								
Total	1	4	22	125	327	212	100	28	9	8	2	1	0	9	33	137	290	161	102	48	32	15	6	2	0	0	1
Percent	0	1	3	15	39	25	12	3	1	1	0	0	0	1	4	16	35	19	12	6	4	2	1	0	0	0	0

+=hygro warmer.

TABLE 10.—*Frequency distribution of temperature differences for Group 3 data (non-adjacent—shelter on roof, hygro on ground), December 1960.*

	Maximum											
	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7
Albuquerque, N. Mex			2	1	9	7	6	6				
Baton Rouge, La					7	7	8	4	4	1		
Billings, Mont				3	11	11	4	2				
Charlotte, N.C			1	1	8	8	3	2				
Chicago, Ill				1	10	7	3	1				
Cleveland, Ohio					4	10	12	4	1			
Colorado Springs, Colo					3	4	6	13	4	1		
Columbus, Ohio		1	2	7	19	2						
Dallas, Tex				2	14	13	2					
El Paso, Tex					3	8	7	8	2	3		
Fargo, N. Dak		1	2	8	13	5	1					
Greenville, S.C	1	4	9	9	8							
Kalispell, Mont					2	4	15	6		1		3
Kansas City, Mo			1	2	5	13	8	2				
Little Rock, Ark			1	1	6	19	3	1				
Louisville, Ky		1		1	5	14	9	1				
Madison, Wis		1	1	5	17	5	2					
Missoula, Mont					5	9	2	5	4	5	1	
Moline, Ill	1			10	15	4	1					
Montgomery, Ala			2	3	8	9	5	3				
Olympia, Wash			4	21	6							
San Angelo, Tex		2	10	17	2							
Sioux City, Iowa		1	1	8	12	2						
Springfield, Mo		1		8	15	5	2					
Toledo, Ohio					3	14	11	3				
Winslow, Ariz				3	4	11	6	4			2	1
Total	1	13	30	83	219	207	123	68	18	11	3	4
Percent	0	2	4	11	28	27	16	9	2	1	0	1

	Minimum												
	+4	+3	+2	+1	0	−1	−2	−3	−4	−5	−6	−7	−8
Albuquerque, N. Mex		3	10	6	4	5	3						
Baton Rouge, La					4	11	10	5	1				
Billings, Mont	1	1	4	12	10	2	1						
Charlotte, N.C				1	7	9	5	1					
Chicago, Ill				2	9	6	2			1	2		
Cleveland, Ohio					6	8	7	4	2	1	2	1	
Colorado Springs, Colo			4	8	12	4	2		1				
Columbus, Ohio		1	3	12	7	3	3		1	1			
Dallas, Tex			1	6	18	5	1						
El Paso, Tex					7	6	9	5	3		1		
Fargo, N. Dak		1		7	12	4	2	3	1				
Greenville, S.C			2	8	6	9	4		2				
Kalispell, Mont				1	2	6	9	4	3	3		2	1
Kansas City, Mo			1	3	3	6	8	6	2	2			
Little Rock, Ark					5	3	5	4	9	2	1		2
Louisville, Ky				2	5	8	9	6		1			
Madison, Wis			1	2	12	10	3	2		1			
Missoula, Mont				1	2	5	1	4	5	9	4		
Moline, Ill					7	11	6	2	2			1	1
Montgomery, Ala			1	9	3	7	8	3					
Olympia, Wash			1	5	11	9	3	2					
San Angelo, Tex		1	7	4	9	5	2	3					
Sioux City, Iowa			1	9	6	4	3		1				
Springfield, Mo				10	11	5	4	1					
Toledo, Ohio					3	7	10	5	3	1	1		
Winslow, Ariz			1	9	4	3	7	6	1				
Total	1	7	37	117	185	161	127	66	37	22	11	4	4
Percent	0	1	5	15	24	21	16	8	5	3	1	1	1

+=hygro warmer

TABLE 11.—*Comparative summarized data for selected months, 1960*

	Distance between instruments (ft.)	Height shelter (ft.)	Height hygro (ft.)	Mean maximum temperature difference (° F.)				Mean minimum temperature difference (° F.)			
				May	July	Oct.	Dec.	May	July	Oct.	Dec.
Group 1. Ground Stations—Adjacent											
Anchorage, Alaska	12	6	4		0.0		0.0		+0.5		+0.7
Duluth, Minn.*	12	7	6			+0.7	+1.2			+0.7	+1.4
Green Bay, Wis	10	5	4			−0.4	−0.7			+0.3	+0.4
Group 2. Ground Stations—Non-Adjacent											
Bismarck N. Dak	3,940	5	5		+0.4		−0.1		−0.5		+0.1
Burlington, Vt	1,246	5.5	5	+0.1	+0.7	+0.4	−0.5	−0.6	−1.7	−2.4	−1.2
Cheyenne, Wyo	1,550	5	5	+2.7	+1.7	+1.0	−1.4	+2.5	+0.9	−0.2	−1.2
Datona Beach, Fla	477	5	5	−0.8	−1.3	−0.7	−0.3	−1.0	−0.3	−0.4	−0.6
Huron, S. Dak	1,962	6	4		+0.7	−0.8	−1.6		−1.1	−2.4	−1.2
Las Vegas, Nev	2,350	5	4	−0.4	−1.0		−1.4	+0.3	+0.4		+0.5
New Orleans, La	2,800	4.5	4	+0.1	−1.4			+3.6	−1.5		
Richmond, Va	2,650	5.7	4.7	+0.2	+0.8		+1.0	+0.3	−1.1		+0.5
Salt Lake City, Utah	3,850	6	4	+0.3	+1.5	−1.0	−1.4	−0.3	+0.5	−1.5	−1.2
Seattle-Tacoma, Wash	1,724	4	4.2	+0.5	+1.0	+0.1	−0.1	+0.1	−0.3	0.0	−0.2
Springfield, Ill	2,000	6	4	−0.7	+1.4	+1.1	−0.5	−0.3	−0.7	−0.3	−1.0
Waterloo, Iowa	1,850	5	5		−0.2		+0.2		−0.8		−0.4
Youngstown, Ohio	1,700	4	4		−0.4	−0.4	−0.3		−0.1	−0.2	+0.4
Group 3. Non-Adjacent—Shelter on Roof, Hygro on Ground											
Albuquerque, N. Mex	4,752	16	5	+0.1	+0.4		−1.0	−0.1	+1.4		+0.7
Cleveland, Ohio	3,940	28	4	−1.5	−1.8		−1.6	−2.3	−3.6		−2.3
Colorado Springs, Colo	1,650	20	6	−1.8	−1.0		−2.5	−0.8	0.0		+0.1
Columbus, Ohio	2,640	39	4	0.0	−0.7		+0.4	+0.4	+0.2		+0.1
Dallas, Tex	1,400	49	5	−0.2	−0.9		−0.5	+0.1	+0.2		0.0
Greenville, S.C	1,850	21	5		+1.4		+1.4		+1.1		−0.4
Kalispell, Mont	1,700	25	4	+1.3	+2.4		−2.5	+0.4	−2.1		−2.7
Little Rock, Ark	2,050	30	5		−0.5		−0.8		−0.9		−3.0
Louisville, Ky	2,145	17	6		−4.6	−2.9	−1.0		−2.3	−2.3	−1.5
Madison, Wis	3,200	28	5	−1.4	−2.9		0.0	−0.8	−1.1		−0.7
Missoula, Mont	1,700	16	6		+2.1		−2.4		−2.7		−3.4
Moline, Ill	2,000	36	5	−0.1	−0.1		−0.7	+0.5	−0.4		−1.7
Montgomery, Ala	2,200	26	4		−1.0		−1.7		+1.6		−0.7
Olympia, Wash	1,660	35	5	+0.8	+1.2		−0.1	+0.4	−1.4		−0.4
San Angelo, Tex	2,080	49	6	+2.8	+4.3		+1.4	−0.6	+1.0		+0.1
Springfield, Mo	1,743	25	5		+0.7		+0.1		−1.7		−0.2
Toledo, Ohio	2,400	20	4		−0.3		−1.4		−1.1		−2.2
Winslow, Ariz	2,050	18	3		+0.9		−1.6		0.0		−1.1

+=hygro warmer.
*Data erroneous because of bad tube in hygro.

TABLE 12.—*Excerpts from correspondence with stations on thermometer exposure.*

A.	Shelter on blacktop and concrete roof, hygro over sand and gravel; vibration by wind shakes down minimum thermometer; prop and jet wash hit shelter.
B.	Shelter on roof with strong radiation, hygro over sod.
C.	Hot air exhaust vent near shelter on roof, hygro over sod.
D.	Shelter between two large paved areas, hygro over sod.
E.	Shelter over gravel soil with sparse grass; concrete and blacktop nearby, also buildings; aircraft warming affects readings.
F.	Shelter on gravel-covered asphalt roof—heating effect from building.
G.	Shelter over heavy sod which is watered in summer.
H.	Spray from cooling tower affects shelter.
I.	Shelter has air conditioning towers and vents nearby, also water 1 to 3 inches on roof most of time.
J.	Watering of grass around shelter lowers temperature.
K.	Shelter on gravel roof with cooling system nearby.
L.	Nearby strip gives occasional jet and prop wash to hygro.
M.	Chinooks cause momentary large changes in temperature. Hygro over ice in winter.
N.	Hygro over poorly drained area.
O.	Drainage ditch with dikes 10–12 feet above hygro; when ditch full, ground around hygro is very wet.
P.	Puddles of water around hygro after rain and thaws.

stations with adjacent installations. They are also greater at those that made both a horizontal and vertical move than at those that made only a horizontal move. The latter differences are again evident in the study for the month of July 1960 at 34 stations and studies for smaller networks for the months of May and October 1960.

These conclusions are again demonstrated by the last three items in table 4. They show a decrease in the percentage of time the readings are in agreement (within 1° F.) from Group 1 to 2 and 2 to 3. This is also demonstrated in figures 3 and 4 which show the probabilities of differences exceeding given amounts.

(2) Values of D_x and D_n are related to synoptic situations, being greatest under conditions of light winds and clear skies and least on days with high-speed winds and overcast skies, as demonstrated in table 7. This indicates that both ventilation and radiation contribute to the differences. The hygro is uniformly ventilated by forced draft and is better able to measure temperature accurately under all conditions.

(3) When the change of instrumentation was accompanied by a change in location (either horizontal or vertical or both) the temperature climatology of that station was quite frequently seriously affected. This is true even though in most cases the hygro location can be considered a better observing site.

It is important that users of temperature data be informed of the wide range of discontinuities introduced by the mass change in instrumental exposures. Monthly mean temperatures have been changed by amounts exceeding 2° F. in many cases, and 3° F. in a few cases. Because of the number of stations involved, the preparation of anomaly charts will be difficult until such time as new station normals can be prepared. Students of climatological trends are warned that the exposure continuity has been disrupted at many stations, and that corrections must be determined and applied. Users of degree-day data are advised that current data cannot be applied to the old normals. Those studying temperature extremes should be aware of the fact that the dozens of extreme records that recently have been broken were not the result of a sudden shift in climate, but of a change in exposures for a large part of the network.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Dr. Helmut E. Landsberg for guidance throughout this study, to Mr. Milton L. Blanc and Dr. J. Murray Mitchell, Jr. for valuable discussions and suggestions, and to Messrs. Albert A. Karpovich and Joseph S. Barry, without whose assistance the large amount of data used for this study could not have been processed.